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(54) **LIQUID CRYSTAL DISPLAY**

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See application file for complete search history.

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(63) Continuation of application No. 12/275,673, filed on Nov. 21, 2008, now Pat. No. 7,995,155.

Notice of Allowance dated Nov. 27, 2013 issued by the KIPO for corresponding Korean patent application No. 10-2007-0121092.

Primary Examiner — Jimmy H Nguyen

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G02F 1/139 (2006.01)
G02F 1/1343 (2006.01)

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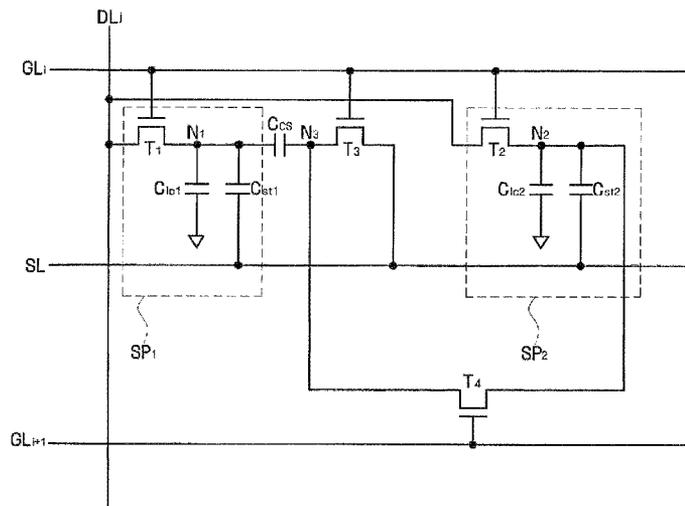
(52) **U.S. Cl.**
CPC **G02F 1/13624** (2013.01); **G09G 3/3659** (2013.01); **G02F 1/1393** (2013.01); **G02F 2001/134345** (2013.01); **G09G 2300/0443** (2013.01); **G09G 2300/0447** (2013.01); **G09G 2300/0814** (2013.01); **G09G 2300/0842** (2013.01); **G09G 2320/068** (2013.01)

(57) **ABSTRACT**

(58) **Field of Classification Search**
CPC . G09G 3/3607; G09G 3/3648; G09G 3/3655; G09G 2300/0809; G09G 2300/0876; G09G 2300/088; G09G 2300/0885; G09G 2300/089

A liquid crystal display includes first and second gate lines arranged in parallel to each other and sequentially transmitting a gate voltage, a data line crossing the first and second gate lines and transmitting a data voltage, a pixel electrode constituted by first and second sub-pixel electrodes and electrically disconnected from each other, a first switching element connected to the first gate line, the data line, and the first sub-pixel electrode, a second switching element connected to the first gate line, the data line, and the second sub-pixel electrode, a third switching element connected to the first sub-pixel electrode across a charge-sharing capacitor, and a fourth switching element connected to the second gate line and the second sub-pixel electrode and connected to the first sub-pixel electrode across the charge-sharing capacitor.

14 Claims, 8 Drawing Sheets



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FIG. 1

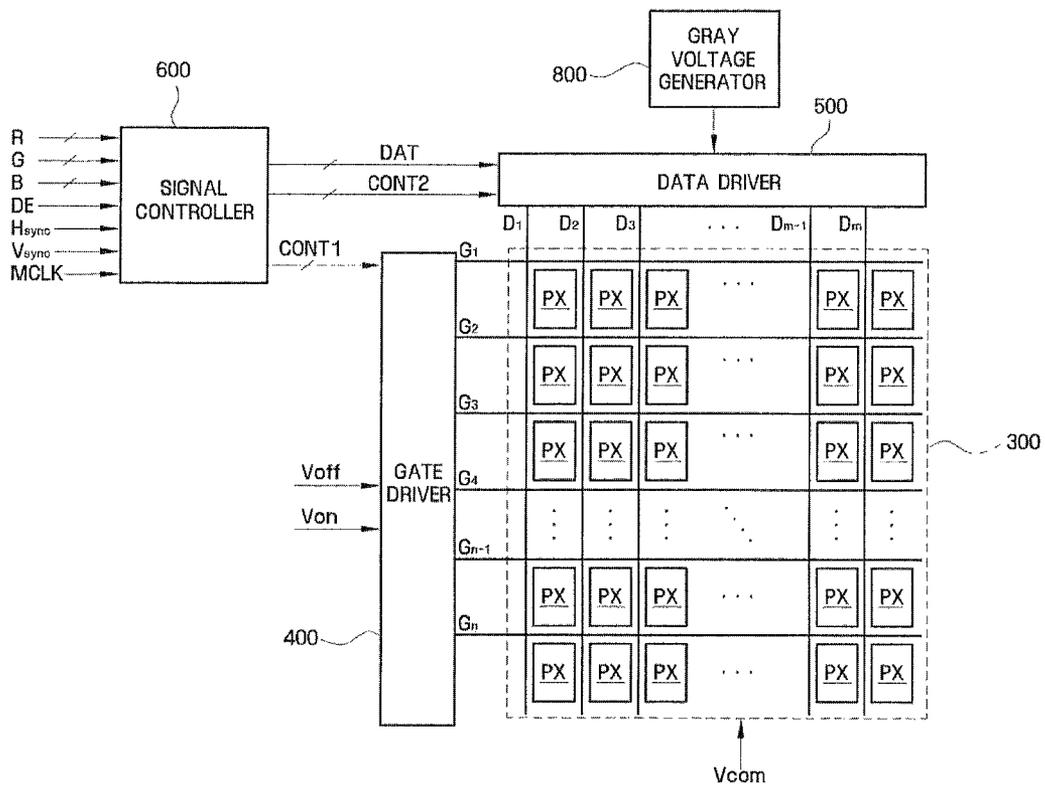


FIG. 2

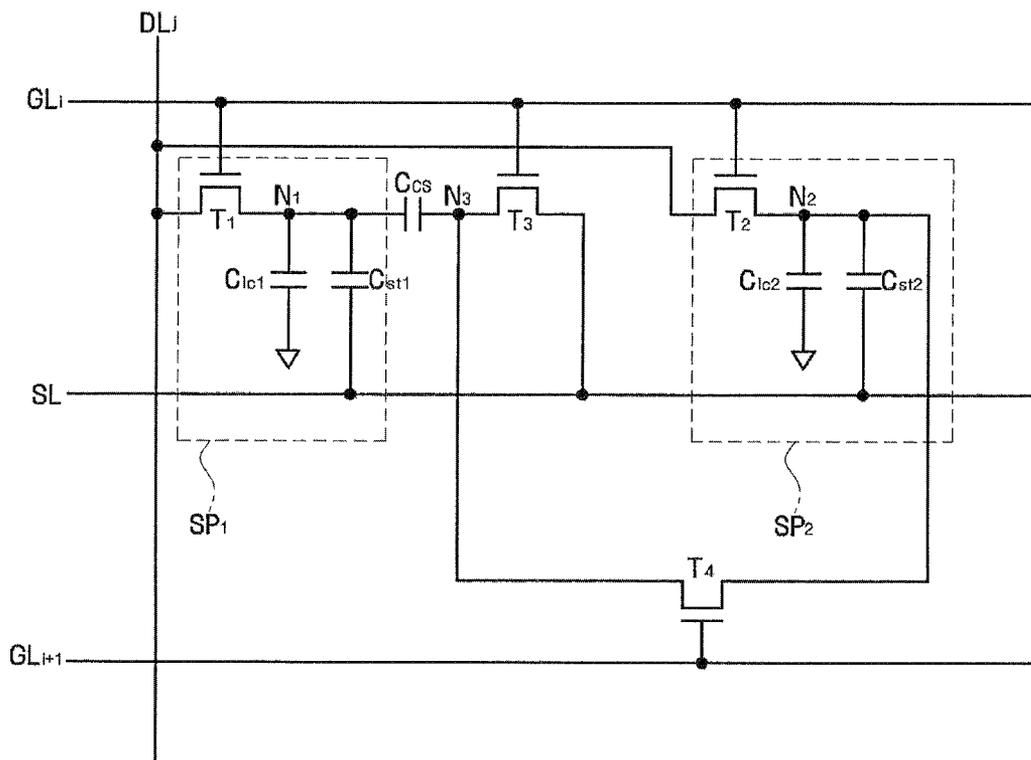


FIG. 3

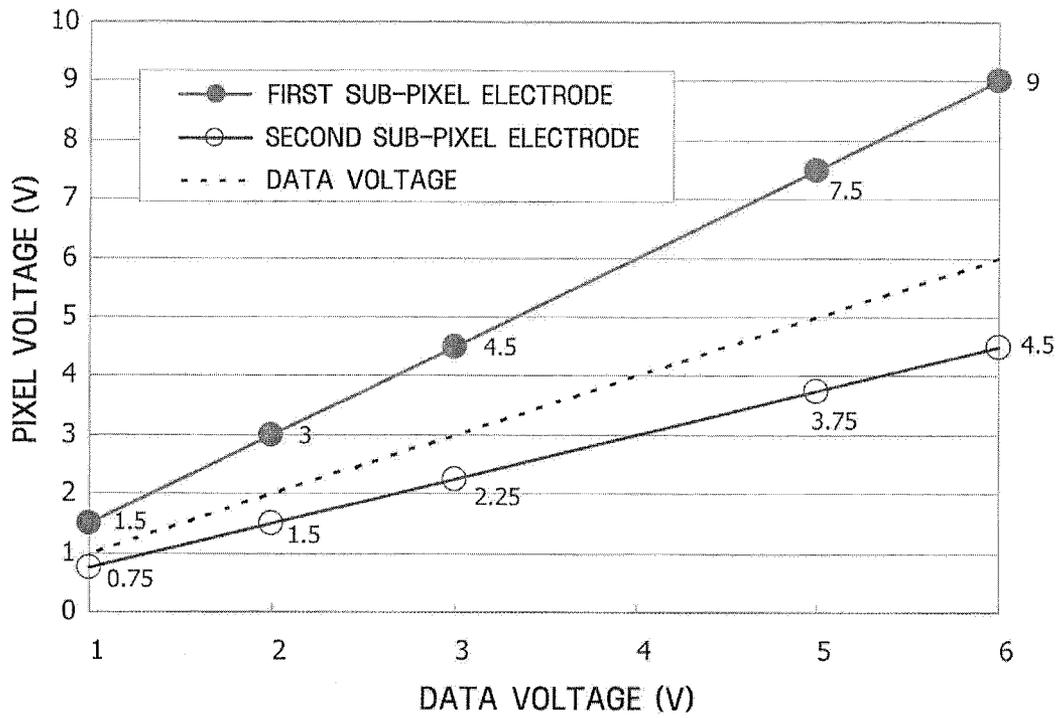


FIG. 4

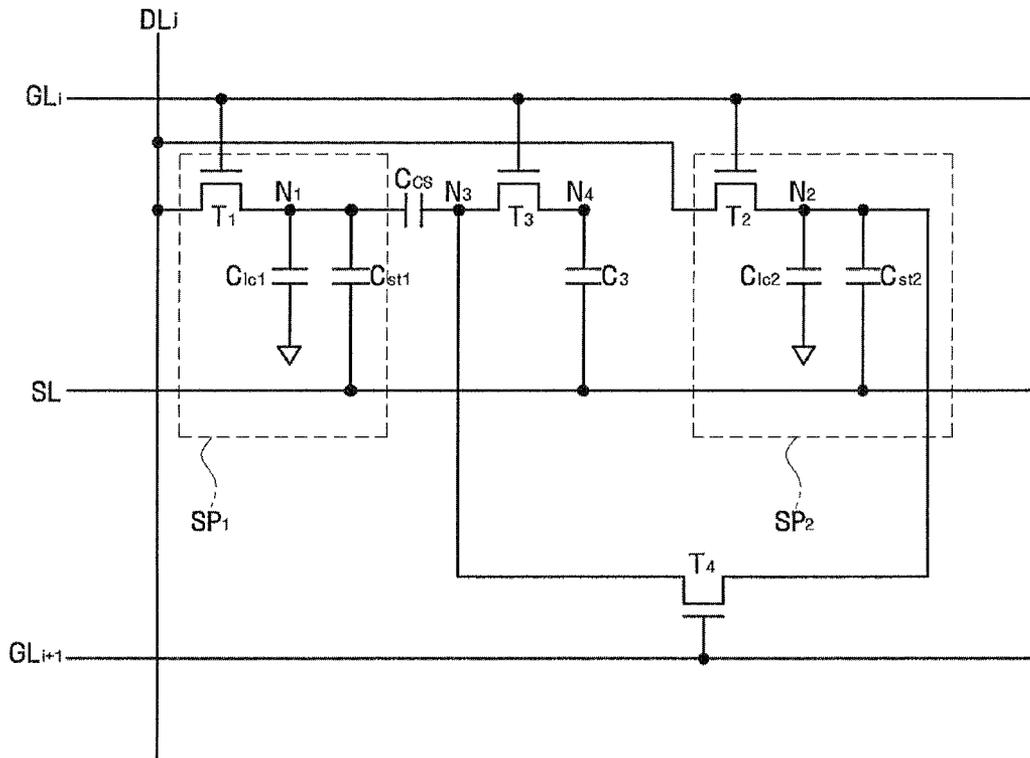


FIG. 5

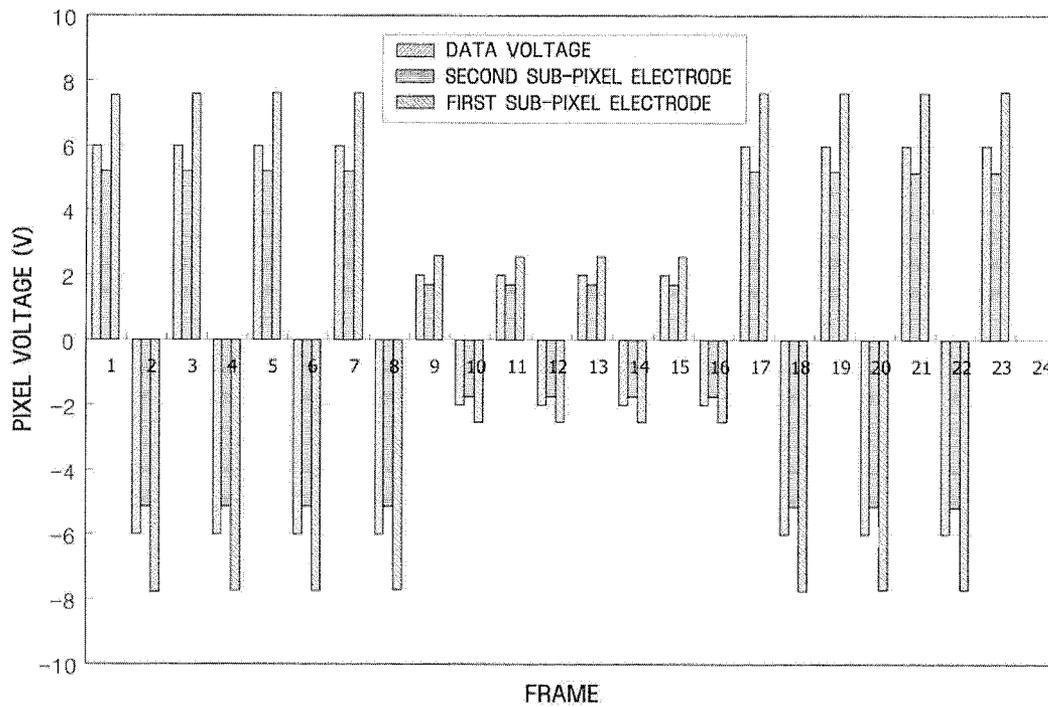


FIG. 6

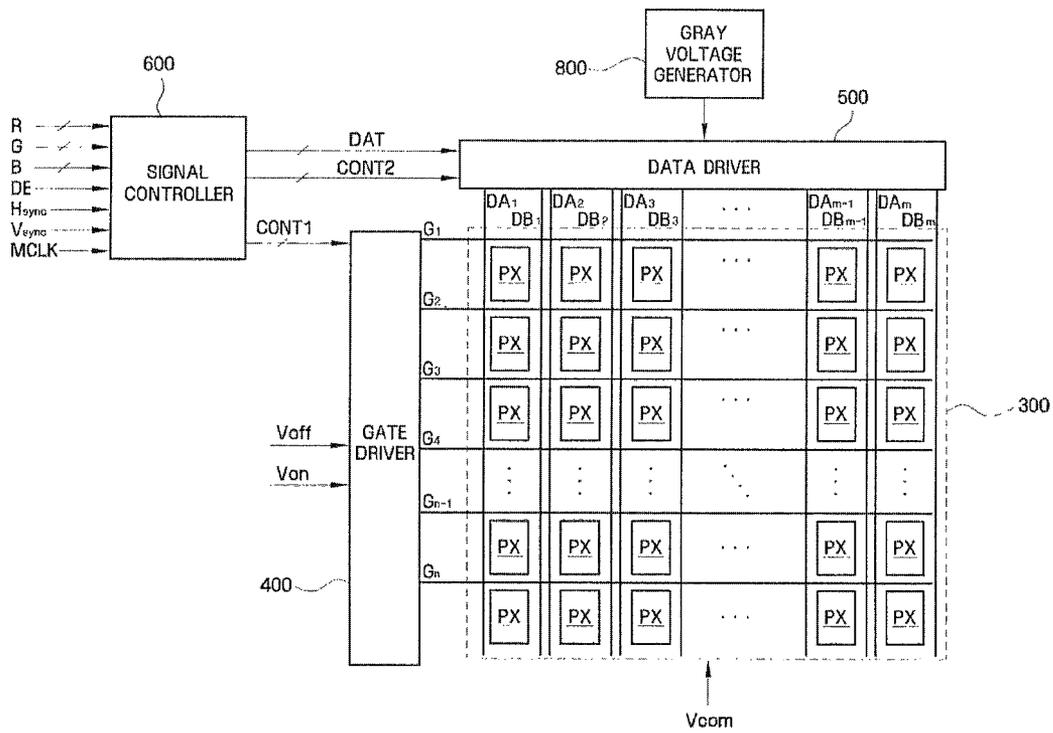


FIG. 7

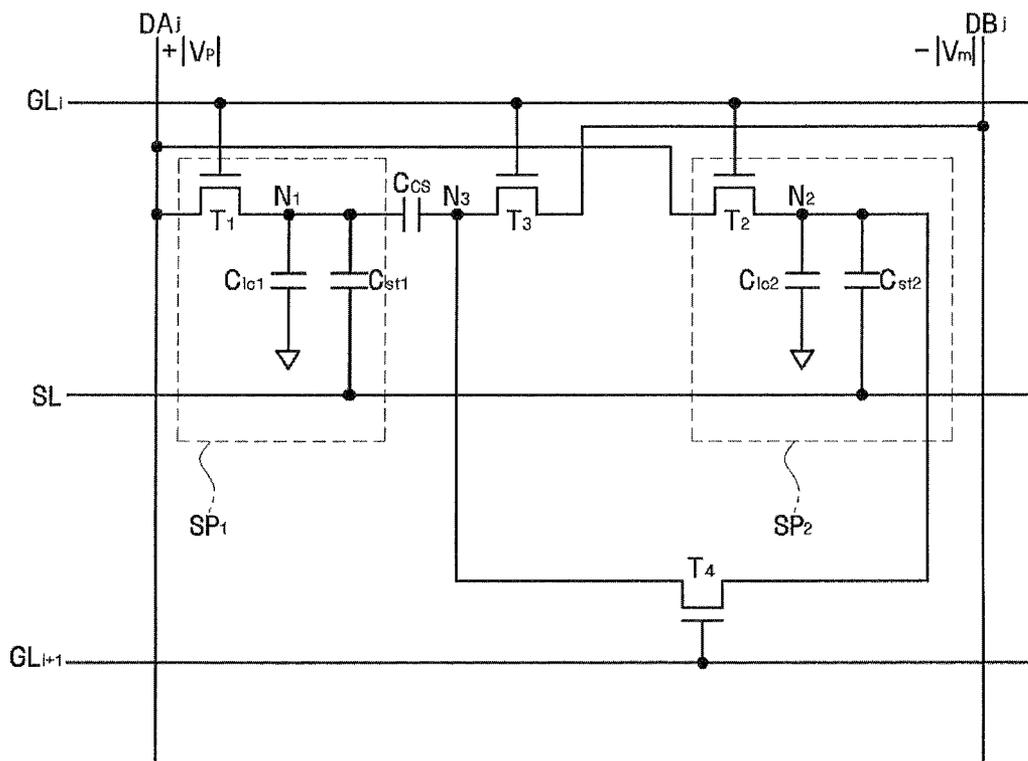
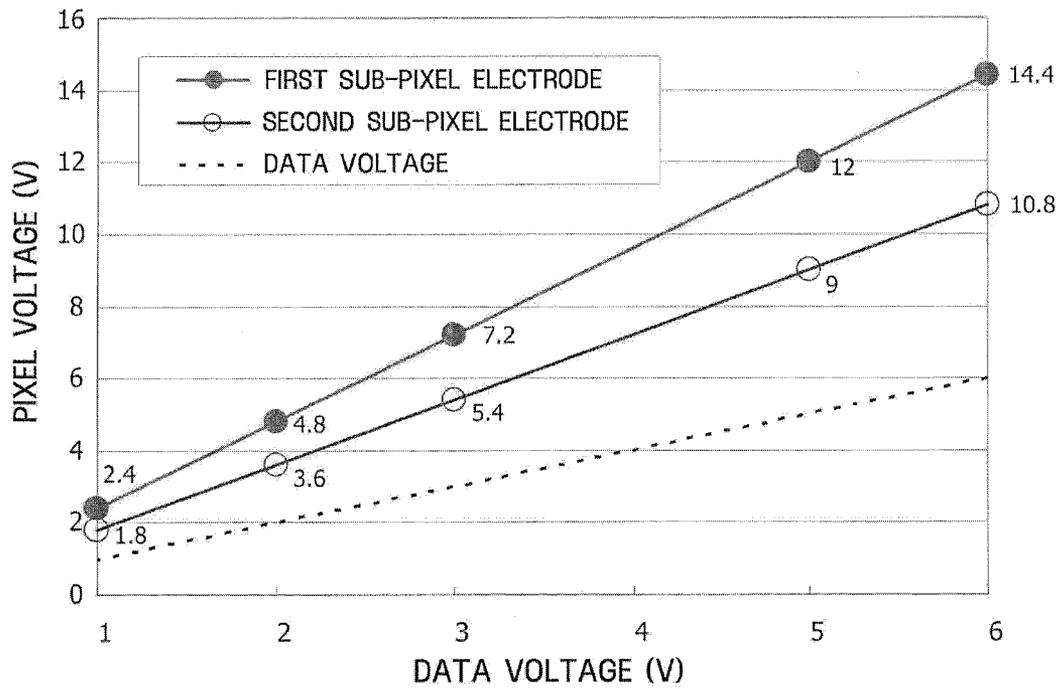


FIG. 8



LIQUID CRYSTAL DISPLAY

CROSS-REFERENCE TO RELATED APPLICATION

This application is a Continuation Application of U.S. patent application Ser. No. 12/275,673, filed Nov. 21, 2008, now U.S. Pat. No. 7,995,155 which claims priority from Korean Patent Application No. 10-2007-0121092 filed on Nov. 26, 2007 in the Korean Intellectual Property Office, the disclosures of which are incorporated herein by reference in their entirety.

BACKGROUND OF THE INVENTION

1. Technical Field

The present invention relates to a display apparatus, and, more particularly, to a liquid crystal display.

2. Discussion of the Related Art

A liquid crystal display is one of the most widely used flat panel displays. Liquid crystal displays include two panels provided with field-generating electrodes such as pixel electrodes and a common electrode and a liquid crystal layer interposed therebetween. The liquid crystal display displays images by applying voltages to the field-generating electrodes to generate an electric field in the liquid crystal layer, which determines orientations of liquid crystal molecules in the liquid crystal layer to adjust polarization of incident light.

A vertical alignment mode liquid crystal display, in which liquid crystal molecules are aligned such that the long axes of the liquid crystal molecules are perpendicular to the two panels (i.e., upper and lower panels) in the absence of an electric field, has become the focus of attention because of its high contrast ratio and wide reference viewing angle, which is defined as a viewing angle making the contrast ratio equal to 1:10 or as a limit angle for the inversion in luminance (brightness) between the grays.

In the vertical alignment mode liquid crystal display, the wide viewing angle can be achieved by forming cutouts in field-generating electrodes and forming protrusions on the field-generating electrodes. Since the cutouts and the protrusions can determine the tilt directions of the liquid crystal LC molecules, the tilt directions can be distributed into several directions by using the cutouts and the protrusions such that the reference viewing angle is widened.

The conventional vertical alignment mode liquid crystal display has relatively poor lateral visibility compared with front visibility. For example, a patterned VA (PVA) mode LCD having the cutouts shows an image that becomes bright as it goes far from the front, and, in the worst case, the luminance difference between high grays vanishes such that the images cannot be perceived.

SUMMARY OF THE INVENTION

Accordingly, embodiments of the present invention provide a liquid crystal display which can prevent a reduction in the brightness of the display while improving lateral visibility.

According to an exemplary embodiment of the present invention, there is provided a liquid crystal display including first and second gate lines arranged in parallel to each other and sequentially transmitting a gate voltage, a data line crossing the first and second gate lines and transmitting a data voltage, a pixel electrode constituted by first and second sub-pixel electrodes electrically disconnected from each other, a first switching element connected to the first gate line,

the data line, and the first sub-pixel electrode, a second switching element connected to the first gate line, the data line, and the second sub-pixel electrode, a third switching element connected to the first sub-pixel electrode across a charge-sharing capacitor, and a fourth switching element connected to the second gate line and the second sub-pixel electrode and connected to the first sub-pixel electrode across the charge-sharing capacitor.

According to another exemplary embodiment of the present invention, there is provided a liquid crystal display including a gate driver driving first and second gate lines arranged in parallel to each other and sequentially transmitting a gate voltage, a data driver driving a data line crossing the first and second gate lines and transmitting a data voltage, a signal controller controlling the gate driver and the data driver, a pixel electrode constituted by first and second sub-pixel electrodes electrically disconnected from each other, a first switching element connected to the first gate line, the data line, and the first sub-pixel electrode, a second switching element connected to the first gate line, the data line, and the second sub-pixel electrode, a third switching element connected to the first sub-pixel electrode across a charge-sharing capacitor; and a fourth switching element connected to the second gate line and the second sub-pixel electrode and connected to the first sub-pixel electrode across the charge-sharing capacitor.

BRIEF DESCRIPTION OF THE DRAWINGS

Exemplary embodiments of the present invention will become apparent by reference to the following detailed description taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is a block diagram of a liquid crystal display according to an exemplary embodiment of the present invention;

FIG. 2 is an equivalent circuit diagram of one pixel of the liquid crystal display shown in FIG. 1;

FIG. 3 is a graph showing the relationship between a data voltage and a pixel voltage in the liquid crystal display shown in FIG. 1;

FIG. 4 is an equivalent circuit diagram of one pixel of a liquid crystal display according to an exemplary embodiment of the present invention;

FIG. 5 is a graph showing the relationship between a data voltage and a pixel voltage in the liquid crystal display shown in FIG. 3;

FIG. 6 is a block diagram of a liquid crystal display according to an exemplary embodiment of the present invention;

FIG. 7 is an equivalent circuit diagram of one pixel of the liquid crystal display shown in FIG. 6; and

FIG. 8 is a graph showing the relationship between a data voltage and a pixel voltage in the liquid crystal display shown in FIG. 6.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

Hereinafter, exemplary embodiments of the present invention will be described in detail with reference to the accompanying drawings. Like reference numerals refer to like elements throughout the specification and drawings.

Referring to FIG. 1, the liquid crystal display includes a liquid crystal panel assembly 300, a gate driver 400 and a data driver 500 operatively connected to the liquid crystal panel assembly 300, a gray-voltage generator 800 operatively connected to the data driver 500, and a signal controller 600 for controlling the gate driver 400 and the data driver 500.

The liquid crystal panel assembly **300** includes a plurality of display signal lines (gate lines G_1 - G_n and data lines D_1 - D_m) and a plurality of pixels PX connected to the signal lines and arranged in a matrix. The liquid crystal panel assembly **300** includes lower and upper panels which face each other and a liquid crystal layer interposed between the panels (not shown).

The display signal lines include a plurality of gate lines G_1 - G_n for transmitting gate signals (also referred to as scan signals) and a plurality of data lines D_1 - D_m for transmitting data signals to individual pixels. The gate lines G_1 - G_n substantially extend in a row (e.g., horizontal) direction and are parallel to each other, and the data lines D_1 - D_m substantially extend in a column (e.g., vertical) direction and are perpendicular to the gate lines G_1 - G_n .

Each pixel PX includes a switching element connected to one of the gate lines G_1 - G_n and to one of the data lines D_1 - D_m , a liquid crystal (LC) capacitor operatively connected to the switching element, and a storage capacitor. The storage capacitor may be cascade-connected to the switching element and the LC capacitor if necessary.

The switching element of each pixel PX is composed of a thin film transistor (TFT) and is a three-terminal element having a control terminal connected to each of the gate lines G_1 - G_n , an input terminal connected to each of the data lines D_1 - D_m , and an output terminal connected to the LC capacitor.

The gate driver **400** is connected to the gate lines G_1 - G_n of the liquid crystal panel assembly **300**, applies the gate signals (composed of a combination of a gate-on voltage V_{on} and a gate-off voltage V_{off}) to the gate lines G_1 - G_n . Although FIG. 1 shows that the gate driver **400** is provided at one side of the liquid crystal panel assembly **300** to be connected to the gate lines G_1 - G_n , the invention is not limited thereto, a pair of gate drivers may be provided at opposite sides of the liquid crystal panel assembly **300** to be connected to the respective gate lines G_1 - G_n at the same time. In a large liquid crystal display, for example, it is difficult to transmit the gate-on voltage V_{on} or the gate-off voltage V_{off} to the gate lines G_1 - G_n using only one gate driver. Thus, a couple of gate drivers are provided at opposite sides of each of the gate lines G_1 - G_n . The gate driver **400** can be incorporated into the lower panel of the liquid crystal assembly **300** as an IC chip having one or more TFTs.

The gray voltage generator **800** generates a gray voltage associated with the transmission of each pixel. The gray voltage is provided to each pixel and has a positive polarity and a negative polarity with respect to a common voltage V_{com} .

The data driver **500** is connected to the data lines D_1 - D_m of the liquid crystal panel assembly **300**, and applies the gray voltage output from the gray voltage generator **800** to each pixel as a data voltage. When the gray voltage generator **800** only provides a predetermined number of reference gray voltages instead of supplying gray voltages for all grays, the data driver **500** generates a gray voltage for all grays by dividing the reference gray voltage, and selects one among them.

The gate driver **400** or the data driver **500** may be integrated in the liquid crystal panel assembly **300** together with the display signal lines G_1 - G_n and D_1 - D_m and TFTs may be mounted on a flexible printed circuit film (not shown) to be attached to the liquid crystal panel assembly **300** in a tape carrier package form.

The data driver **500** can be mounted directly on a liquid crystal panel assembly **300** as an IC chip. Alternatively, the data driver **500** can be attached on the liquid crystal panel assembly **300** as a TCP by being mounted on a flexible printed circuit film (not shown).

The signal controller **600** controls the gate driver **400** and the data driver **500**

The signal controller **600** receives an input control signal including a vertical synchronization signal V_{sync} , a horizontal synchronizing signal H_{sync} , a main clock signal MCLK, a data enable signal DE, and others, from an external graphics controller (not shown) for controlling display of input image signals R, G and B. The signal controller **600** processes image signals R, G and B based on the input image signals R, G, and B and the input control signals received by the signal controller **600** to be suitable to an operating condition of the liquid crystal panel assembly **300**. Then, the signal controller **600** generates a gate control signal CONT1 and a data control signal CONT2, and outputs them to the gate driver **400** and data driver **500**, respectively.

The gate control signal CONT1 includes a scan start signal STV indicating the start of an operation, e.g., scanning, of the gate driver **400**, and at least one clock signal for controlling output time of the gate-on voltage V_{on} . The gate control signal CONT1 may further include an output enable signal OE for defining the duration of the gate-on voltage V_{on} .

The data control signal CONT2 includes a horizontal synchronization start signal STH that indicates that valid data is transmitted to a row of pixels, a load signal LOAD for applying the respective data voltages to the data lines D_1 - D_m , and a data clock signal HCLK. The data control signal CONT2 may further include a reverse signal RVS for reversing the polarity of the data voltage with respect to the common voltage V_{com} , which is referred to as the "polarity of the data voltage" hereinafter.

The data driver **500** receives image data DAT for each pixel PX, selects gray voltages corresponding to the image data DAT supplied from the gray voltage generator **800** in response to the data control signals CONT2 from the signal controller **600**, converts the image data DAT into corresponding data voltages, and applies the converted data voltages to the respective data lines D_1 - D_m .

The gate driver **400** sequentially applies the gate-on voltage V_{on} to the gate lines G_1 - G_n and turns ON the switching elements connected to the gate lines G_1 - G_n in accordance with the gate control signal CONT1 output from the signal controller **600**. The data voltages applied to the data lines D_1 - D_m are applied to each pixel PX through the turned-ON switching elements.

The difference between the common voltage V_{com} and the data voltage applied to the data line of each pixel PX is applied across the pixel and appears as a charge voltage of the LC capacitor, that is, a pixel voltage. The arrangement (orientations) of liquid crystal molecules varies depending on the size of the pixel voltage and thus the polarization of the light passing through the liquid crystal layer varies. The liquid crystal molecules have orientations depending on the magnitude of the pixel voltage and the orientations determine the polarization of light passing through the LC capacitor.

In the liquid crystal display according to an exemplary embodiment of the present invention, after applying the same data voltage to a pair of sub pixels constituting each pixel PX, the gate-on voltage V_{on} is applied to a gate line adjacent to the gate line corresponding to the pair of sub pixels. In this case, the data voltage charged in either one of the sub pixels is decreased by charge sharing. Since the sub pixels of the same pixel electrode are charged with different voltages, a gamma curve of a pixel PX becomes a merged gamma curve of the two sub pixels. When the data voltages charged in the respective sub pixels are determined by charge sharing, the frontal merged gamma curve is made to be close to the frontal reference gamma curve, and the lateral merged gamma curve is made to be closest to the frontal reference gamma curve and

the frontal merged gamma curve of the two sub pixels is close to the frontal reference gamma curve, thereby improving lateral visibility.

Referring to FIG. 2, the liquid crystal display according to an exemplary embodiment of the present invention includes a plurality of gate lines GL_1 - GL_{i+1} transmitting a gate signal and a plurality of data lines DL_j crossing the gate lines GL_1 - GL_{i+1} and transmitting a data signal.

Each pixel PX includes a first sub pixel SP_1 and a second sub pixel SP_2 . The first sub pixel SP_1 includes a first switching element T_1 , a first LC capacitor C_{lc1} and a first storage capacitor C_{st1} , and the second sub pixel SP_2 includes a second switching element T_2 , a second LC capacitor C_{lc2} and a second storage capacitor C_{st2} , respectively.

A first switching element T_1 and a second switching element T_2 are formed at an intersection point of an i th gate line GL_i and an n th data line DL_j , a third switching element T_3 connected to the i th gate line GL_i , and a fourth switching element T_4 is connected to the $(i+1)$ th gate line GL_{i+1} . The first through fourth switching elements may be thin film transistors (TFTs).

The first switching element T_1 has a control terminal connected to the i th gate line GL_i , an input terminal connected to a j th data line DL_j , and an output terminal connected to the first LC capacitor C_{lc1} and the first storage capacitor C_{st1} . The second switching element T_2 has a control terminal connected to the i th gate line GL_i , an input terminal connected to a j th data line DL_j , and an output terminal connected to the second LC capacitor C_{lc2} and the second storage capacitor C_{st2} . The third switching element T_3 has a control terminal connected to the i th gate line GL_i , an output terminal connected to the output terminal of the first switching element T_1 with a charge-sharing capacitor C_{CS} interdisposed therebetween, and an input terminal connected to a storage line SL. In more detail, the input terminal of the third switching element T_3 is directly connected to the storage line SL. The fourth switching element T_4 has a control terminal connected to the $(i+1)$ th gate line GL_{i+1} , an input terminal connected to the output terminal of the second switching element T_2 , and an output terminal connected to the output terminal of the third switching element T_3 . Accordingly, the output terminal of the fourth switching element T_4 is connected to the output terminal of the first switching element T_1 with the charge-sharing capacitor C_{CS} interposed therebetween.

Each pixel PX includes a pixel electrode consisting of a first sub-pixel electrode connected to the output terminal of the first switching element T_1 , and a second sub-pixel electrode connected to the output terminal of the second switching element T_2 . A common electrode is provided on the upper panel facing the lower panel.

The first LC capacitor C_{lc1} includes a first sub-pixel electrode connected to the first switching element T_1 , a common electrode, and liquid crystals interposed therebetween. The first storage capacitor C_{st1} includes a first sub-pixel electrode, a storage electrode line SL that is provided on the lower panel with an insulator disposed therebetween.

The second LC capacitor C_{lc2} includes a second sub-pixel electrode connected to the second switching element T_2 , a common electrode, and liquid crystals interposed therebetween. The second storage capacitor C_{st2} includes a second sub-pixel electrode, a storage electrode line SL that is provided on the lower panel, and an insulator disposed between the second sub-pixel electrode and the storage electrode line SL.

The charge-sharing capacitor C_{CS} includes an output terminal of the first switching element T_1 , an output terminal of the third switching element T_3 , and an insulator disposed

therebetween. The charge-sharing capacitor C_{lc2} and the third switching element T_3 function to decrease the pixel voltages charged in the second LC capacitor C_{lc2} while increasing the pixel voltages charged in the first LC capacitor C_{lc1} .

The first storage capacitor C_{st1} and the second storage capacitor C_{st2} sustain pixel voltages charged in the first LC capacitor C_{lc1} and the second LC capacitor C_{lc2} , respectively. A fixed voltage, e.g., a common voltage V_{com} , is applied to the storage line SL.

If a gate-on signal V_{on} is applied to the i th gate line GL_i , a data voltage of the same level is transmitted to the first and second sub-pixel electrodes in the i th row of pixels through the first switching element T_1 and the second switching element T_2 . That is, the same data voltage is charged in the first LC capacitor C_{lc1} and the second LC capacitor C_{lc2} connected to the i th gate line GL_i . The data voltage charged in the first LC capacitor C_{lc1} and the second LC capacitor C_{lc2} is referred to as a pixel voltage.

If a gate-on voltage V_{on} is applied to the i th gate line GL_i , the third switching element T_3 is turned on and the common voltage V_{com} is transmitted to the output terminal of the third switching element T_3 . Thus, a voltage corresponding to a difference between the data voltage and the common voltage V_{com} is charged in the charge-sharing capacitor C_{CS} .

If a gate-off voltage V_{off} is then applied to the i th gate line GL_i , the first sub pixel SP_1 and the second sub pixel SP_2 are electrically disconnected from each other. That is, after a data voltage of the same level is applied to the first sub-pixel electrode and the second sub-pixel electrode, the first sub-pixel electrode and the second sub-pixel electrode are maintained at a floating state.

If the gate-on signal V_{on} is applied to the $(i+1)$ th gate line GL_{i+1} , a data voltage of the same level is transmitted a pair of second sub-pixel electrodes in the $(i+1)$ th row of pixels through a first switching element (not shown) and a second switching element (not shown) connected to the $(i+1)$ th gate line GL_{i+1} .

In addition, if the gate-on signal V_{on} is applied to the $(i+1)$ th gate line GL_{i+1} , the fourth switching element T_4 is turned on. Accordingly, the data voltage stored in the second sub-pixel electrode connected to the second switching element T_2 is distributed to the charge-sharing capacitor C_{CS} through the fourth switching element T_4 . This is because the input terminal of the fourth switching element T_4 is connected to the output terminal of the second switching element T_2 and the output terminal of the fourth switching element T_4 is connected to the charge-sharing capacitor C_{CS} . Accordingly, data voltages stored in the first sub-pixel electrode and the second sub-pixel electrode in the i th row of pixels and connected to the first switching element T_1 and the second switching element T_2 will have different levels.

Next, pixel voltages of the first sub-pixel electrode and the second sub-pixel electrode will be described in detail using the principle of conservation of charge. Here, a first node N_1 is a node between the output terminal of the first switching element T_1 and the charge-sharing capacitor C_{CS} , a second node N_2 is a node between the output terminal of the second switching element T_2 and the input terminal of the fourth switching element T_4 , a third node N_3 is a node between the charge-sharing capacitor C_{CS} and the output terminal of the third switching element T_3 . The third node N_3 may also be a node between the charge-sharing capacitor C_{CS} and the output terminal of the fourth switching element T_4 .

If the gate-on signal V_{on} is applied to the i th gate line GL_i , the first switching element T_1 and the second switching element T_2 are turned on so that a data voltage V_d is applied to the first node N_1 and the second node N_2 . As the third switch-

ing element T_3 is turned on, the common voltage V_{com} is applied to the third node N_3 . For explanatory convenience, it is assumed that a common voltage V_{com} is 0 V, a data voltage Vd is defined as a relative voltage with respect to the common voltage V_{com} . Therefore, voltages applied to a first node N_1 , a second node N_2 and a third node N_3 are Vd , Vd , and 0, respectively. It is also assumed that the capacitance sum of the first LC capacitor C_{lc1} and the first storage capacitor C_{st1} is denoted by Ch , the capacitance sum of the second LC capacitor C_{lc2} and the second storage capacitor C_{st2} is denoted by Cl , and the capacitance of the charge-sharing capacitor C_{CS} is denoted by Cb .

The quantity of charge Qh corresponding to the capacitance sum of the first LC capacitor C_{lc1} and the first storage capacitor C_{st1} , the quantity of charge Ql corresponding to the capacitance sum of the second LC capacitor C_{lc2} and the second storage capacitor C_{st2} , and the quantity of charge Qb of the charge-sharing capacitor C_{CS} are given by the following equation (1):

$$Qh = Ch \times Vd$$

$$Ql = Cl \times Vd$$

$$Qb = Cb \times Vd$$

Next, if the gate-off voltage $Voff$ is applied to the i th gate line GL_i and the gate-on signal Von is applied to the $(i+1)$ th gate line GL_{i+1} , the first switching element T_1 , the second switching element T_2 and the third switching element T_3 are turned off and the fourth switching element T_4 is turned on.

Assuming that voltages applied to the first node N_1 , the second node N_2 and the third node N_3 are $V1$, $V2$ and $V3(=V2)$, respectively, the quantity of charge Qh' corresponding to the capacitance sum of the first LC capacitor C_{lc1} and the first storage capacitor C_{st1} , the quantity of charge Ql' corresponding to the capacitance sum of the second LC capacitor C_{lc2} and the second storage capacitor C_{st2} , and the quantity of charge Qb' of the charge-sharing capacitor C_{CS} are given by the following equation (2):

$$Qh' = Ch \times V1$$

$$Ql' = Cl \times V2$$

$$Qb' = Cb \times (V1 - V2)$$

Since total quantity of charge in capacitors connected to the first node N_1 is conserved, the following equation (3) is satisfied:

$$Qh + Qb = Qh' + Qb'$$

Since total quantity of charge in capacitors connected to the third node N_3 is conserved, the following equation (4) is satisfied:

$$Ql - Qb = Ql' - Qb'$$

Based on the relationships (1) through (4), the voltages $V1$ and $V2$ applied to the first node N_1 and the second node N_2 can be obtained using the following equation (5):

$$V1 = Vd \left(1 + \frac{Cl \cdot Cb}{Cl \cdot Ch + Ch \cdot Cb + Cb \cdot Cl} \right)$$

$$V2 = Vd \left(1 - \frac{Ch \cdot Cb}{Cl \cdot Ch + Ch \cdot Cb + Cb \cdot Cl} \right)$$

If a data voltage Vd is a positive-polarity voltage greater than the common voltage V_{com} (e.g., 0 V), the pixel voltage $V1$ of the first sub pixel SP_1 rises compared to the data voltage

Vd , while the pixel voltage $V2$ of the second sub pixel SP_2 drops compared to the data voltage Vd . In contrast, if a data voltage Vd is a negative-polarity voltage smaller than the common voltage V_{com} (e.g., 0 V), the pixel voltage $V1$ of the first sub pixel SP_1 drops compared to the data voltage Vd , while the pixel voltage $V2$ of the second sub pixel SP_2 rises compared to the data voltage Vd . Accordingly, the absolute value of the pixel voltage $V1$ of the first sub pixel SP_1 is larger than that of the pixel voltage $V2$ of the second sub pixel SP_2 all the time.

As described above, if the pixel voltages $V1$ and $V2$ applied to the first sub pixel SP_1 and the second sub pixel SP_2 constituting one and the same pixel are different from each other, the lateral visibility can be improved. Sets of gray voltages having different gamma curves obtained from image information are stored in the first sub pixel SP_1 , and a gamma curve of a pixel constituted by the first sub pixel SP_1 and the second sub pixel SP_2 is close to the merged gamma curve of the first and second sub pixels SP_1 and SP_2 . Accordingly, when determining the sets of gray voltages, the frontal merged gamma curve is preferably made to be close to the frontal reference gamma curve and the lateral merged gamma curve is preferably made to be closest to the frontal reference gamma curve, thereby improving the lateral visibility.

FIG. 3 is a graph showing a change in the pixel voltage of a first sub-pixel electrode and a second sub-pixel electrode with respect to the data voltage applied across data lines shown in FIG. 1, in which the pixel voltage is calculated based on the charge ratio $Cl:Ch:Cb=2:1:2$, for example.

As shown in FIG. 3, when a data voltage applied to data lines is 6 V, the pixel voltage of the first sub-pixel electrode is 9 V, as represented by the plotted line (---), increased by 3V, while the pixel voltage of the second sub-pixel electrode is 4.5 V, as represented by the plotted line (-o-), decreased by 1.5 V. Therefore, a sufficiently large difference can be obtained between the pixel voltages charged in the first and second sub-pixel electrodes. In particular, since a difference between the pixel voltage of the second sub-pixel electrode and the data voltage, as represented by the dotted line, is not sufficiently large, a sharp reduction in the brightness can be suppressed.

Hereinafter, a liquid crystal display according to an exemplary embodiment of the present invention will be described in detail with reference to FIGS. 4 and 5. FIG. 4 is an equivalent circuit diagram of one pixel of a liquid crystal display according to an exemplary embodiment of the present invention, and FIG. 5 is a graph showing the relationship between a data voltage and a pixel voltage in the liquid crystal display shown in FIG. 3. For explanatory convenience, components each having the same function for describing the exemplary embodiment shown in FIGS. 1 through 3 are respectively identified by the same reference numerals, and their detailed descriptions will not be repeated.

Referring to FIG. 4, a third switching element T_3 has a control terminal connected to an i th gate line GL_i , an output terminal connected to the output terminal of a first switching element T_1 with a charge-sharing capacitor C_{CS} disposed therebetween, and an input terminal connected to a storage line SL . In more detail, the input terminal of the third switching element T_3 is directly connected to the storage line SL with an auxiliary capacitor C_3 disposed therebetween. The input terminal of the third switching element T_3 and the storage line SL , which are formed at different layers in the LCD manufacturing process, are quite difficult to be directly coupled to each other. In such a case, the auxiliary capacitor C_3 may be used for coupling the input terminal of the third switching element T_3 to the storage line SL .

Next, pixel voltages of the first sub-pixel electrode and the second sub-pixel electrode will be described in detail using the principle of conservation of charge. Here, a fourth node N_4 is a node between the input terminal of the third switching element T_3 and the auxiliary capacitor C_3 . For explanatory convenience, it is assumed that a common voltage V_{com} is 0V, a data voltage Vd is defined as a relative voltage with respect to the common voltage V_{com} , and the capacitance of an auxiliary capacitor C_3 is denoted by Cc .

In addition, assuming that voltages applied to a first node N_1 , a second node N_2 , a third node N_3 and a fourth node N_4 are $V1$, $V2$, $V3$, and $V4$, respectively, for an $(n-1)$ th frame, $V2=V3$. The quantity of charge Qh corresponding to the capacitance sum of the first LC capacitor C_{lc1} and the first storage capacitor C_{st1} , the quantity of charge $Q1$ corresponding to the capacitance sum of the second LC capacitor C_{lc2} and the second storage capacitor C_{st2} , the quantity of charge Qb of the charge-sharing capacitor C_{CS} , and the quantity of charge Qc of the auxiliary capacitor C_3 are given by the following equation (6):

$$Qh = Ch \times V1$$

$$Q1 = Cl \times V2$$

$$Qb = Cb \times (V1 - V3) = Cb \times (V1 - V2)$$

$$Qc = Cc \times V4$$

If the gate-on signal Von is applied to the i th gate line GL_i for an n th frame, the first switching element T_1 and the second switching element T_2 are turned on so that the data voltage Vd is applied to the first node N_1 and the second node N_2 . As the third switching element T_3 is turned on, the third node N_3 and the fourth node N_4 are connected to each other. Here, assuming that voltages of the first node N_1 , the second node N_2 , the third node N_3 , and the fourth node N_4 are $V1'$, $V2'$, $V3'$, and $V4'$, respectively, $V1'=V2'=Vd$, and $V3'=V4'$.

In this case, the quantity of charge Qh' corresponding to the capacitance sum of the first LC capacitor C_{lc1} and the first storage capacitor C_{st1} , the quantity of charge $Q1'$ corresponding to the capacitance sum of the second LC capacitor C_{lc2} and the second storage capacitor C_{st2} , the quantity of charge Qb' of the charge-sharing capacitor C_{CS} , and the quantity of charge Qc' of the auxiliary capacitor C_3 are given by the following equation (7):

$$Qh' = Ch \times V1' = Ch \times Vd$$

$$Q1' = Cl \times V2' = Cl \times Vd$$

$$Qb' = Cb \times (V1' - V3') = Cb \times (Vd - V3')$$

$$Qc' = Cc \times V4' = Cc \times V3'$$

Since the total quantity of charge in capacitors connected to the third node N_3 and the fourth node N_4 is conserved, the following relationship given by the equation (8) is satisfied:

$$Qc - Qb = Qc' - Qb'$$

Next, if a gate-off voltage $Voff$ is applied to the i th gate line GL_i and the gate-on signal Von is applied to the $(i+1)$ th gate line GL_{i+1} , the first switching element T_1 , the second switching element T_2 and the third switching element T_3 are turned off and the fourth switching element T_4 is turned on.

Assuming that voltages of the first node N_1 , the second node N_2 , the third node N_3 , and the fourth node N_4 are $V1''$, $V2''$, $V3''$ and $V4''$, respectively, $V2''=V3''$. In this case, the quantity of charge Qh'' corresponding to the capacitance sum of the first LC capacitor C_{lc1} and the first storage capacitor

C_{st1} , the quantity of charge $Q1''$ corresponding to the capacitance sum of the second LC capacitor C_{lc2} and the second storage capacitor C_{st2} , the quantity of charge Qb'' of the charge-sharing capacitor C_{CS} , and the quantity of charge Qc'' of the auxiliary capacitor C_3 are given by the following equation (9):

$$Qh'' = Ch \times V1''$$

$$Q1'' = Cl \times V2''$$

$$Qb'' = Cb \times (V1'' - V3'') = Cb \times (V1'' - V2'')$$

$$Qc'' = Cc \times V4''$$

Since the total quantity of charge in capacitors connected to the first node N_1 is conserved, the following equation (10) is satisfied:

$$Qh' + Qb' = Qh'' + Qb''$$

Since the total quantity of charge in capacitors connected to the third node N_3 is conserved, the following equation (11) is satisfied:

$$Q1' + Qc' - Qb' = Q1'' + Qc'' - Qb''$$

Based on the equations (6) through (11), the voltages $V1''$ and $V2''$ applied to the first node N_1 and the second node N_2 can be obtained using the following equation (12):

$$V1'' = Vd + (Vd - V0) \frac{Cl \cdot Cb}{Cl \cdot Ch + Ch \cdot Cb + Cb \cdot Cl}$$

$$V2'' = Vd - (Vd - V0) \frac{Ch \cdot Cb}{Cl \cdot Ch + Ch \cdot Cb + Cb \cdot Cl}$$

Here,

$$V0 = \frac{(Cb \cdot Vd + Cc \cdot V4) - Cb(V1 - V2)}{Cb + Cc}$$

Therefore, if the data voltage Vd is a positive-polarity voltage greater than the common voltage V_{com} (e.g., 0V), the pixel voltage $V1''$ of the first sub pixel SP_1 rises compared to the data voltage Vd , while the pixel voltage $V2''$ of the second sub pixel SP_2 drops compared to the data voltage Vd . In contrast, if the data voltage Vd is a negative-polarity voltage smaller than the common voltage V_{com} (e.g., 0V), the pixel voltage $V1''$ of the first sub pixel SP_1 drops compared to the data voltage Vd , while the pixel voltage $V2''$ of the second sub pixel SP_2 rises compared to the data voltage Vd . Accordingly, the absolute value of the pixel voltage $V1''$ of the first sub pixel SP_1 is larger than that of the pixel voltage $V2''$ of the second sub pixel SP_2 all the time.

As described above, if the pixel voltages $V1''$ and $V2''$ applied to the first sub pixel SP_1 and the second sub pixel SP_2 constituting one and the same pixel are different, the lateral visibility can be improved.

FIG. 5 is a graph showing a change in the pixel voltage of a first sub-pixel electrode and a second sub-pixel electrode with respect to the data voltage applied across data lines for each frame, in which the pixel voltage is calculated based on the charge ratio $Cl:Ch:Cb:Cc=2:1:0.8:2$ and the data voltage changes from 6V to 2V to 6V, for example.

As shown in FIG. 5, the pixel voltage of the first sub pixel SP_1 rises compared to the data voltage Vd , while the pixel voltage of the second sub pixel SP_2 drops compared to the data voltage Vd . Accordingly, a sufficient difference between the pixel voltages of the first sub-pixel electrode and the second sub-pixel electrode can be obtained. In particular, since a difference between the pixel voltage of the second

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sub-pixel electrode and the data voltage is not sufficiently large, a sharp reduction in the brightness can be suppressed.

Hereinafter, a liquid crystal display according to an exemplary embodiment of the present invention will be described with reference to FIGS. 6 through 8. FIG. 6 is a block diagram of a liquid crystal display according to a third exemplary embodiment of the present invention, FIG. 7 is an equivalent circuit diagram of one pixel of the liquid crystal display shown in FIG. 6, and FIG. 8 is a graph showing the relationship between a data voltage and a pixel voltage in the liquid crystal display shown in FIG. 6. For explanatory convenience, components each having the same function for describing the exemplary embodiment shown in FIGS. 1 through 3 are respectively identified by the same reference numerals, and their detailed descriptions will not be repeated.

Referring to FIG. 6, in the equivalent circuit, the liquid crystal panel assembly 300 includes a plurality of display signal lines (gate lines G_1 - G_n and data lines D_1 - D_m) and a plurality of pixels PX connected to the signal lines and arranged in a matrix. The liquid crystal panel assembly 300 includes lower and upper panels which face each other and a liquid crystal layer interposed between the panels.

The plurality of display signal lines are provided on the lower panel and include a plurality of gate lines G_1 - G_n for transmitting gate signals, a plurality of data lines DA_1 - DA_m for transmitting data signals, and a plurality of charge-sharing wires DB_1 - DB_m for transmitting charge sharing signals to switching elements. The gate lines G_1 - G_n substantially extend in a row direction and are substantially parallel to one another. The data lines DA_1 - DA_m extend in a column direction and are substantially parallel to one another. The charge-sharing wires DB_1 - DB_m extend in a direction substantially perpendicular to the data lines DA_1 - DA_m .

Referring to FIG. 7, the liquid crystal display according to an exemplary embodiment, unlike the liquid crystal display previously described, a charge-sharing wire DB_j is formed to be substantially parallel to a data line DA_j in each pixel. The third switching element T_3 has a control terminal connected to the i th gate line GL_i , an output terminal connected to the output terminal of the first switching element T_1 with a charge-sharing capacitor C_{CS} interposed therebetween, and an input terminal connected to the charge-sharing wire DB_j . A data voltage (e.g., $+|Vp|$), which is a positive-polarity data and is greater than the common voltage V_{com} , is applied to the data line DA_j , and a charge-sharing voltage (e.g., $-|Vm|$), which is negative-polarity data and is smaller than the common voltage V_{com} , is applied to the charge-sharing wire DB_j . Here, the positive-polarity voltage means a voltage greater than the common voltage V_{com} , and the negative-polarity voltage means a voltage smaller than the common voltage V_{com} .

Although in the previously described exemplary embodiment, the common voltage V_{com} is applied to the input terminal of the third switching element T_3 (that is, $V_{com}=0V$), here, a charge-sharing voltage smaller than the common voltage V_{com} , e.g., $-|Vm|$, is applied to the input terminal of the third switching element T_3 . Therefore, if the gate-on voltage V_{on} is applied to the i th gate line GL_i and the third switching element T_3 is turned on, a voltage $|Vp|+|Vm|$ is charged in the charge-sharing capacitor C_{CS} . Therefore, charge sharing for the first sub pixel SP_1 and the second sub pixel SP_2 is more effectively performed. As the pixel voltage calculation results, as described above in the exemplary embodiment described in connection with FIGS. 1-3, pixel voltages charged in the first sub-pixel electrode and the second sub-pixel electrode, that

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is, voltages $V1$ and $V2$ of first and nodes N_1 and N_2 , can be given by the following equation (13):

$$V1 = |Vp| + (|Vp| + |Vm|) \frac{Cl \cdot Cb}{Cl \cdot Ch + Ch \cdot Cb + Cb \cdot Cl} + 2|Vm| \frac{Cb \cdot Cb}{Cl \cdot Ch + Ch \cdot Cb + Cb \cdot Cl}$$

$$V2 = |Vp| - (|Vp| - |Vm|) \frac{Ch \cdot Cb}{Cl \cdot Ch + Ch \cdot Cb + Cb \cdot Cl} + 2|Vm| \frac{Cb \cdot Cb}{Cl \cdot Ch + Ch \cdot Cb + Cb \cdot Cl}$$

It can be deduced from the relationship (13) that the pixel voltage $V1$ of the first sub pixel SP_1 rises relative to the data voltage $|Vp|$ and the pixel voltage $V2$ of the second sub pixel SP_2 drops relative to the pixel voltage $V1$ of the first sub pixel SP_1 .

Further, not only the pixel voltage $V1$ of the first sub pixel SP_1 but also the pixel voltage $V2$ of the second sub pixel SP_2 may rise relative to the data voltage $|Vp|$, if the following equation (14) is satisfied:

$$\frac{|Vm|}{|Vp|} \geq \frac{Ch}{2Cb + Ch}$$

As shown in equation (14), unless $|Vm|$ is much less than $|Vp|$, the pixel voltages $V1$ and $V2$ can be boosted in most cases. In such cases, even if a low data voltage is supplied from a data driver, two different pixel voltages having a large level can be produced at the first sub pixel SP_1 and the second sub pixel SP_2 . In a general VA (vertical alignment) mode liquid crystal display requiring a high-level data voltage, if an appropriate charge-sharing voltage is applied to the third switching element T_3 through the charge-sharing wire DB_j , a high-level pixel voltage can be obtained even by a small data voltage. Here, the polarity of the charge-sharing voltage is preferably opposite to the polarity of the data voltage. For example, if a data voltage is a positive-polarity voltage, the charge-sharing voltage is preferably a negative-polarity voltage, if the data voltage is a negative-polarity voltage, the charge-sharing voltage is preferably a positive-polarity voltage.

The operation described above may be also true for a case where the data voltage is a negative-polarity voltage smaller than the common voltage V_{com} .

FIG. 8 is a graph showing a change in the pixel voltage of a first sub-pixel electrode and a second sub-pixel electrode with respect to the data voltage applied across data lines, in which the pixel voltage is calculated based on the charge ratio $Cl:Ch:Cb=2:1:2$, for example.

As shown in FIG. 8, when a data voltage applied to data lines is 6 V, the pixel voltage of the first sub-pixel electrode increases to 14.4 V, as represented by the plotted line (—•—), and the pixel voltage of the second sub-pixel electrode also increases to 10.8 V, as represented by the plotted line (—○—). Therefore, a sufficiently large difference can be obtained between the pixel voltages charged in the first and second sub-pixel electrodes while boosting the pixel voltages of the first and second sub-pixel electrodes. Therefore, a reduction in the brightness can be prevented.

As described above, a pixel electrode is divided into a pair of sub-pixel electrodes to produce a difference in the pixel voltage between the pair of sub-pixel electrodes by charge

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sharing, thereby improving the lateral visibility. In addition, a switching element is connected to one end of a charge-sharing capacitor, which makes a difference in the pixel voltage between the pair of sub-pixel electrodes, thereby further improving the lateral visibility. Further, the switching element functions to prevent the pixel voltage from sharply decreasing compared to the data voltage, thereby suppressing a reduction in the brightness by charge sharing.

While exemplary embodiments of the present invention have been described for illustrative purposes, it will be understood by those of ordinary skill in the art that various changes in form and details are possible without departing from the spirit and scope of the disclosure.

What is claimed is:

1. A display device comprising:
 - a gate line;
 - a data line crossing the gate line;
 - a pixel electrode comprising a first sub-pixel electrode and a second sub-pixel electrode;
 - a first switching element electrically connected to the gate line, the data line, and the first sub-pixel electrode;
 - a second switching element electrically connected to the gate line, the data line, and the second sub-pixel electrode; and
 - a third switching element electrically connected to the gate line, the first sub-pixel electrode, and a conductive line carrying a common voltage,
 wherein the third switching element is electrically connected to the first sub-pixel electrode via an electrical connection through a charge-sharing capacitor, wherein one terminal of the charge-sharing capacitor is directly connected to the first sub-pixel electrode and another terminal of the charge-sharing capacitor is directly connected to a terminal of the third switching element, wherein the conductive line is directly connected to a first storage capacitor being different from the charge-storage capacitor and being directly connected to the one terminal of the charge-sharing capacitor and the first sub-pixel electrode, and wherein the electrical connection is not through the first switching element, the conductive line, and the gate line.
2. The display device of claim 1, wherein a voltage of the first sub-pixel electrode is different from a voltage of the second sub-pixel electrode.
3. The display device of claim 2, wherein the first sub-pixel electrode and the second sub-pixel electrode are insulated from each other.
4. The display device of claim 3, wherein the conductive line is a storage line.
5. The display device of claim 2, wherein the conductive line is a storage line.
6. The display device of claim 1, wherein the first sub-pixel electrode and the second sub-pixel electrode are insulated from each other.

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7. The display device of claim 6, wherein the conductive line is a storage line.

8. The display device of claim 1, wherein the conductive line is a storage line.

9. The display device of claim 1, wherein the charge-sharing capacitor is formed by an output terminal of the first thin film transistor, an output terminal of the third thin film transistor, and an insulator between the output terminal of the first switching element and the output terminal of the third switching element.

10. The display device of claim 9, wherein the third switching element is directly connected to the conductive line via an input terminal of the third switching element.

11. A display device comprising:
 - a gate line;
 - a data line crossing the gate line;
 - a pixel electrode comprising a first sub-pixel electrode and a second sub-pixel electrode;
 - a first thin film transistor comprising a first terminal connected to the gate line, a second terminal connected to the data line, and a third terminal connected to the first sub-pixel electrode;
 - a second thin film transistor comprising a first terminal connected to the gate line, a second terminal connected to the data line, and a third terminal connected to the second sub-pixel electrode; and
 - a third thin film transistor comprising a first terminal connected to the gate line, a second terminal connected to the third terminal of the first thin film transistor via an electrical connection through a charge-sharing capacitor, and a third terminal connected to a conductive line carrying a common voltage,
 wherein one terminal of the charge-sharing capacitor is directly connected to the first sub-pixel electrode and another terminal of the charge-sharing capacitor is directly connected to the second terminal of the third thin film transistor, wherein the conductive line is directly connected to a first storage capacitor being different from the charge-storage capacitor and being directly connected to the one terminal of the charge-sharing capacitor and the first sub-pixel electrode, and wherein the electrical connection is not through the first thin film transistor, the conductive line, and the gate line.
12. The display device of claim 11, wherein the conductive line is a storage line.
13. The display device of claim 11, wherein the charge-sharing capacitor is formed by the third terminal of the first thin film transistor, the second terminal of the third thin film transistor, and an insulator between the second terminal of the third thin film transistor and the third terminal of the first thin film transistor.
14. The display device of claim 13, wherein the third terminal of the third thin film transistor is directly connected to the conductive line.

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